SOLARIMETERS AND SOLARIGRAPHS

SIMPLE INSTRUMENTS FOR DIRECT READINGS OF SOLAR RADIATION INTENSITY FROM SUN AND SKY

LADISLAUS GORCZYŃSKI, D. Sc.

[Washington, October 28, 1926]

SYNOPSIS

The paucity of solar radiation data is chiefly due to the lack of simple and portable instruments for direct readings. To fill this lack, there is described, under the name of "Solarimeter," a combination of a thermopile (modified Moll type), closed hermetically, under a hemispherical glass cover, and directly combined with an electrical measuring apparatus of a simple millivoltmeter type. A system of two contact screws makes it easy to employ the solarimeter either for sun and sky observations on a horizontal surface or for pyrheliometric readings at normal incidence. For the latter a small pyrheliometric tube on a special holder is connected with the solarimeter box. All these new constructions should be considered as secondary instruments, which necessitate comparisons with normal pyrheliometers.

Directions for using and testing the solarimeter are given, in which is emphasized the employment of a solar screen for determining the sky radiation by Doctor Kimball's method.

A recording solarimeter (solarigraph) is also briefly discussed and the importance of sun and sky radiation measurements emphasized not only for meteorological stations, but also for agriculturists, botanists, for aviation (transparency of the atmosphere), and finally for photographic and medical purposes, by using violet and ultra-violet filters.

GENERAL REMARKS

Meteorologists are in full accord that in the series of meteorological elements solar radiation takes the predominant place. Nevertheless, we note the strange fact that of the many thousand meteorological stations in the world a totally negligible number are making solar radiation measurements. In the large and well developed network in the United States only about six stations are making pyrheliometric readings or records regularly, and in other countries or continents the proportion is still lower.

The reason for this very unsatisfactory state of things is not an underestimation of the importance of solar radiation for the study of the atmosphere and its changes, but rather the lack of simple instruments for direct readings of this predominant meteorological element. It is obvious that for daily observations at ordinary meteorological stations and for general use for those interested (agriculturists, botanists, medical men, etc.) only very simple, portable, and robust instruments can be employed. One needs an apparatus that will directly indicate the momentary values of radiation intensity like a thermometer or other direct reading instrument. This objective is nearly gained by using thermopiles for solar radiation work.

The first thermoelectric pyrheliograph was used by Crova, professor at the University of Montpellier (France), some 40 years ago. Similar apparatus using thermopiles, recording or direct reading, but based on the thermoelectrical method, were constructed by Féry, Moll, Kalitine, Dorno, and recently by Linke, Henry, and others. Those usually employed at meteorological stations and research observatories are the Weather Bureau thermoelectric recording pyrheliometer devised in 1923 by Kimball and Hobbs at Washington, and the thermoelectric pyrheliograph constructed in Europe and described in the MONTHLY WEATHER REVIEW (June, 1924) by the writer. But recorders intended for automatic notation of solar radiation values must necessarily possess a recording galvanometer with a clock mechanism, and in addition—for pyrheliographs recording radiation at normal incidence—a special equatorial mounting with another clock permitting it to follow the sun. Although by no means too difficult for regular use, all these recorders are relatively expensive and require daily service, which prohibits their use at simple meteorological stations.

The solarimeter is particularly adapted for stations of not only the higher order, but also for the simplest observing points.

On account of the extraordinary simplicity of reading the solarimeter, the new instrument makes possible the realization of the wish of meteorologists of all countries to include solar radiation measurements in daily routine observations, made at the same time as regular readings of air temperature, pressure, wind, etc.

Solarimeters are, moreover, especially useful in all sunny lands, such as the tropical and equatorial regions. Indeed, the best example of the great need of simple solar radiation apparatus is the fact that the greater part of the meteorological stations in India are at present equipped with the so-called "radiation thermometers," consisting of a black bulb in vacuo. Only the existing extreme lack of simple apparatus for direct readings of solar radiation can explain why the "radiation thermometers" are still used, notwithstanding their well-known and very serious meteorological defects.

Another important feature of the solarimeter is its adaptability for use with light filters. By employing a special solution, as, for example, copper sulphate in distilled water, the intensity of the violet and ultra-violet part of the spectrum can easily be obtained. Such an adaptation is especially valuable for medical climatology, actinotherapy, and also for photography, as it may be used for determining the proper time exposure. In addition to the copper-sulphate filters for shorter wave lengths, other light filters may be used. For the infra-red portion of the spectrum, marble glass is very efficient. Further information concerning the question of light filters may be found in the paper "Light-filter measurements made by the Polish Solar Radiation Expedition to Siam in 1923, and at Touggourt in the Sahara Desert in 1924," published in the Quarterly Journal of the Royal Meteorological Society (pp. 210–218, vol. 51, April, 1926, London).

Finally, it is possible to apply solarimeters for aviation by connecting them with sensitive galvanometers; in this case one can rapidly obtain an idea of the transparency and thickness of clouds and fogs.

We give below the description of new direct-reading instruments, which are very simple even for the most inexperienced observers and several times less expensive[1] than the pyrheliographs. To these direct-reading instruments, designed for both solar and sky radiation, we propose to give the name of "Solarimeters" in order to distinguish them from pyrheliometers, which serve generally for radiation intensity of the sun at normal incidence.

[1] While *thermoelectric recorders* cost in round figures from $300 to $500, the solarimeters can be obtained for about $65 in Paris, where they are regularly manufactured by Richard, using the solarimetric thermopiles made by Kipp at Delft, Holland. The European construction would certainly be improved by combining the solarimetric thermopiles with American-made millivoltmeters, in view of the excellence of the latter instruments manufactured in the United States.

THE SOLARIMETER: SOME DETAILS OF ITS CONSTRUCTION

The great simplicity of the solarimeter is evident by inspecting Figures 1 and 2. This portable little instrument for measuring solar radiation consists of an hermetically closed (in dry air) brass cylinder containing a solarimetric thermopile under a hemispherical cover of special flint glass and directly connected with a convenient needle galvanometer of simple millivoltmeter type. The characteristic feature of the solarimeter is that its thermoelectric elements generating the current under the influence of solar radiation are directly attached to the galvanometric system (magnet with moving coil and needle), so that these two essential portions forming the complete apparatus are placed in the same solarimeter box. The cylinder, with the thermopile, being fitted on the inner cover of the box, all connections are made inside.

The thermopiles especially made for solarimetric use consist of very thin plates of manganin and constantan of low resistance (about 8 ohms), with active junctions placed on a straight line in the center. In comparison with the original Moll type, it must be noted that the thermoelements forming the rectangular solarimetric pile are straightened and uniformly covered with a special lacquer layer without intervals between separate thermoelements. This special construction and new arrangement of thermoelements with an unbroken and plane surface is essential for solarimetric work in order to avoid the changing influence of the oblique sun's rays resulting from their different incidence angles between horizon and zenith.

Though the solarimeter is designed primarily for direct readings of both sun and sky radiation, by merely changing the contact screws it is possible to connect the galvanometer, contained in the solarimeter box, with a pyrheliometer tube mounted in a special holder. With the tube normally directed to the sun, we thus obtain immediately a direct-reading pyrheliometer

The details of this construction are shown on the diagram, Figure 1.

The pyrheliometric tubes used in connection with the solarimeter box are placed on a special holder (fig. 2.); the operation of directing them normally to the solar rays is very easily carried out by viewing a spot of light from the sun on the sight placed in the tube.

The thermopile used in the pyrheliometric tube is the same as that for solarimetric use, but without a hemispherical glass cover. In the opposite end of the pyrheliometric tube is a sphero-cylindrical lens, which magnifies the galvanometer deflections about four times.

The use of this lens is not obligatory, and an ordinary plane protecting glass would be sufficient to obtain good deflections. But the use of a sphero-cylindrical lens is not only very useful with low radiation values (and especially when employing light filters), but has other important advantages. The spherical and cylindrical radii are so calculated that the sun's rays are focused in the form of a narrow line covering just the active junctions of the thermopile, and by means of a rectangular diaphragm placed in the middleof the pyrheliometric tube the greater part of the thermopile remains in shadow.

Readings of the solarimeter are scarcely more complicated than the observation of an ordinary radiation thermometer. For making a measurement the box is placed horizontally, the slide in the cover opened, and the first determination of zero on the galvanometer scale made. One need not bring the needle to the true zero of the scale. The slide is then closed, the cover opened to expose the thermopile, and the deflection of the galvanometer needle again read. The thermopile itself acts in less than two seconds, but the final deflection of the needle is reached after a somewhat longer period, due to the lag introduced by the thick glass hemisphere. The cover is then closed, the slide opened, and the second

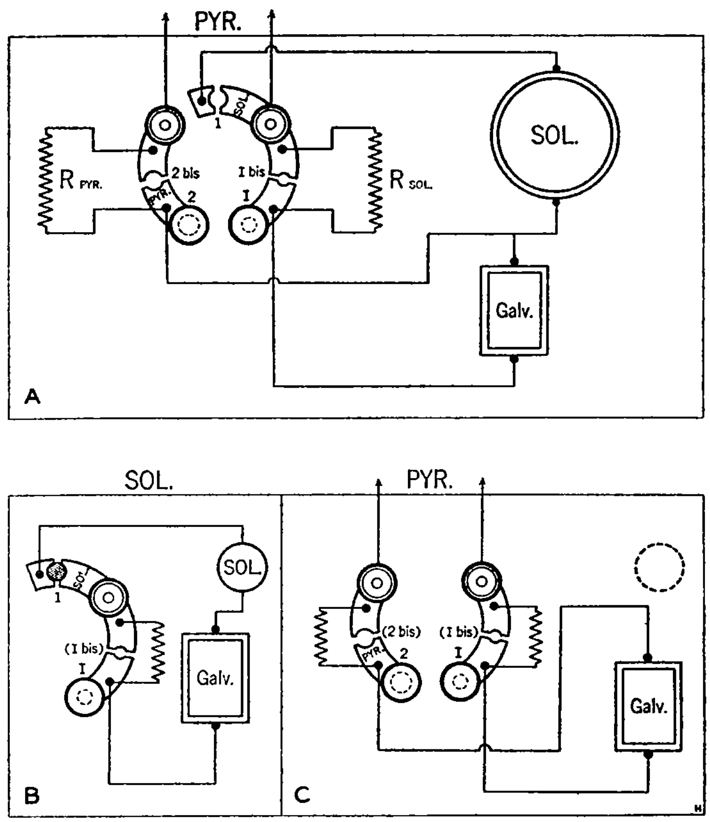

FIG. 1.—Diagram of connections in the solarimeter box

EXPLANATION OF SIGNS

Diagram A

Sol.—Solarimetric thermopile under hemispherical glass cover.
Galv.—Magnet with movable coil and needle.
1, 2, 2_{bis}.—Alternative positions of the larger contact screw.
I, I_{bis}.—Alternative positions of the smaller contact screw.
In the positions 2 and I the contact screws are in their neutral positions, and do not influence the electrical connections of the apparatus.
R_{sol} and R_{pyr}.—Additional resistances which can be eliminated by putting in I_{bis} and 2_{bis}, the respective contact screws.
Two circles with arrows each represent two contacts where the leads for pyrheliometric connections should be attached.

Diagram B.—Connections for solarimetric readings; 1 and I for ordinary use

For ordinary use the larger contact screw is placed at 1, the smaller one at I (its neutral position). With this position of the two contacts, the additional resistance R_{sol} is included. If the smaller contact is removed from 1 to I_{bis}, the additional resistance is eliminated. The increase of the galvanometer deflection is, however, moderate in this case, the resistance R_{sol} being relatively small and chiefly used to give to the coefficient a certain desired value.

Diagram C.—Connections for pyrheliometric readings: 2 and I for ordinary use

Two movable contact screws remain in their neutral positions (smaller screw at I, large one at 2). With this position the additional resistance R_{sol} and R_{pyr} are both included. If the contact screws are removed from 2 to 2_{bis} and from I to I_{bis}, respectively, the two additional resistances are both eliminated. The galvanometer deflection is very largely increased in this case and such a combination may be used for small radiation values or when employing light filters. Other possible combinations (as, for example, 2_{bis} and I) are of secondary interest and will be only occasionally used; for every such combination a special coefficient must be determined in order to be able to convert the respective deflections into absolute value.

determination of zero made as before. In case the zero readings differ, their mean value should be subtracted from the deflection produced by sun and sky. The differences are due in part to a slight heating of the glass hemisphere during the observation (due to the relatively great thickness and volume of the glass); time is necessary, therefore, to permit the needle to return to its true zero.

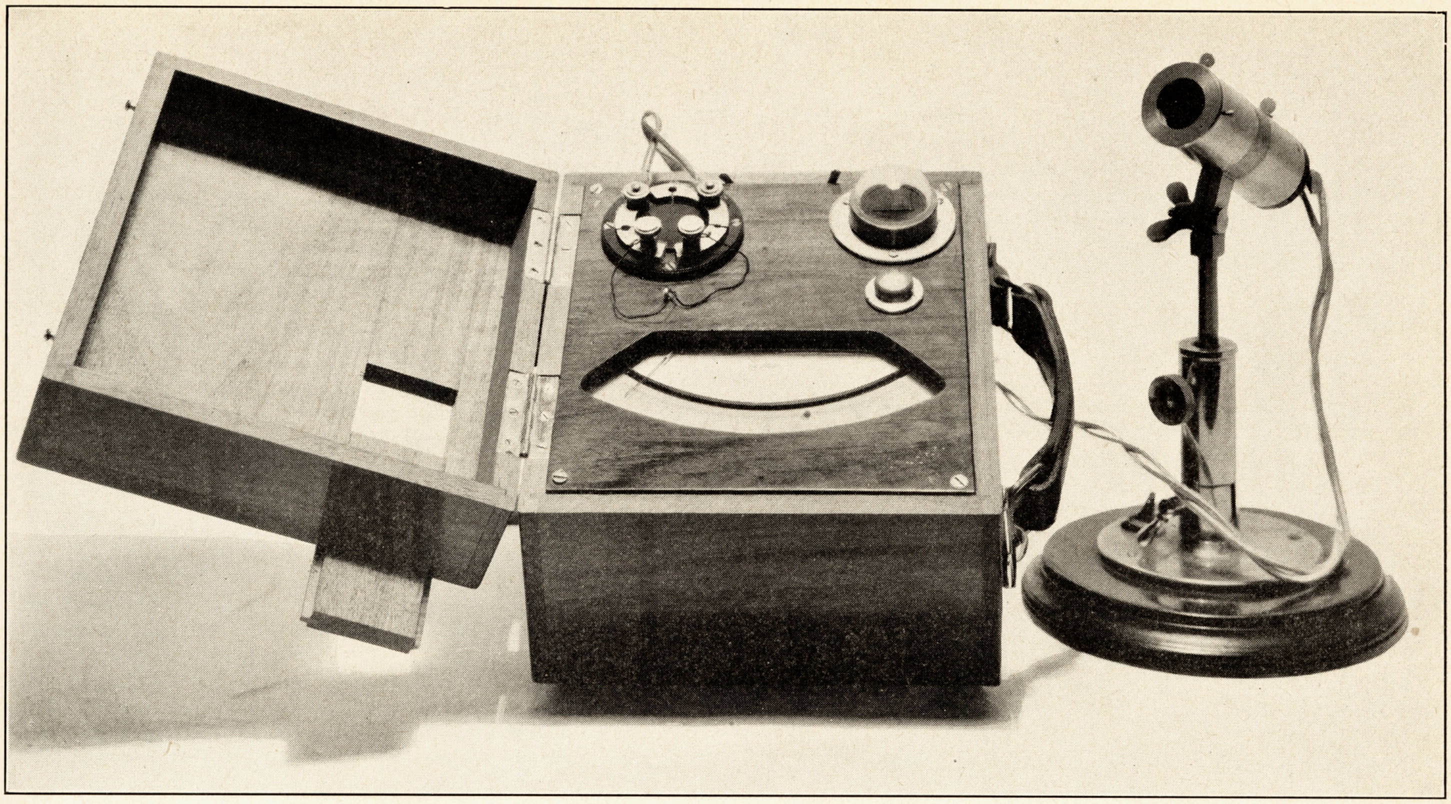

FIG. 2.—Solarimeter box for direct readings of the sun and sky radiation on a horizontal surface (connected also with a pyrheliometric tube on stand for the sun radiation intensity at normal incidence)

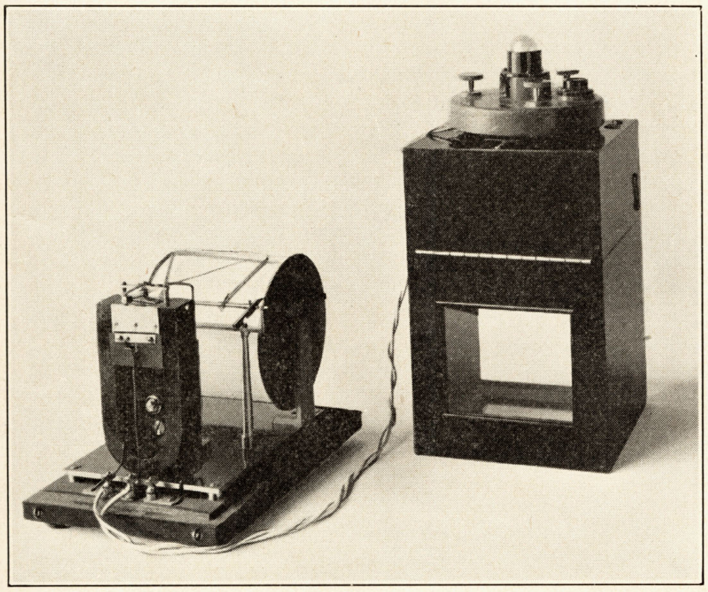

FIG. 3.—Solarigraph: Solarimetric pile under glass cover exposed outdoors to the sun and sky radiation and connected by leads with a recording millivoltmeter installed indoors

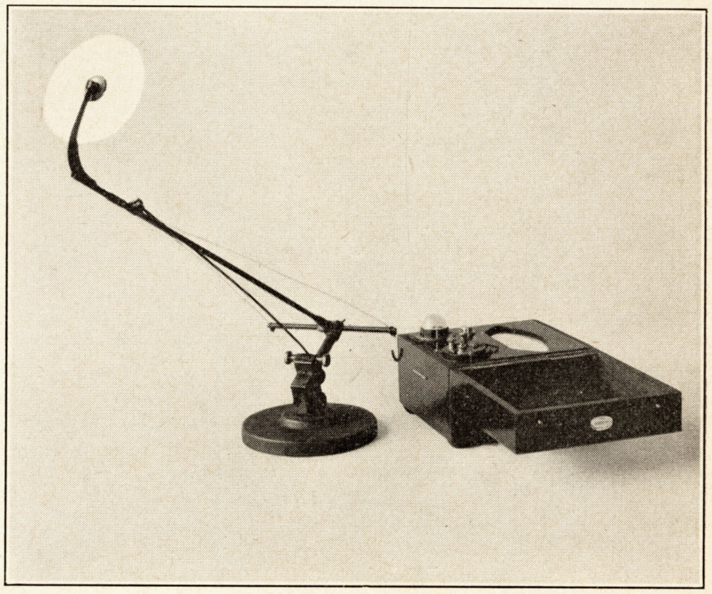

FIG. 4.—Solar screen used in connection with solarimeter for readings of sky radiation

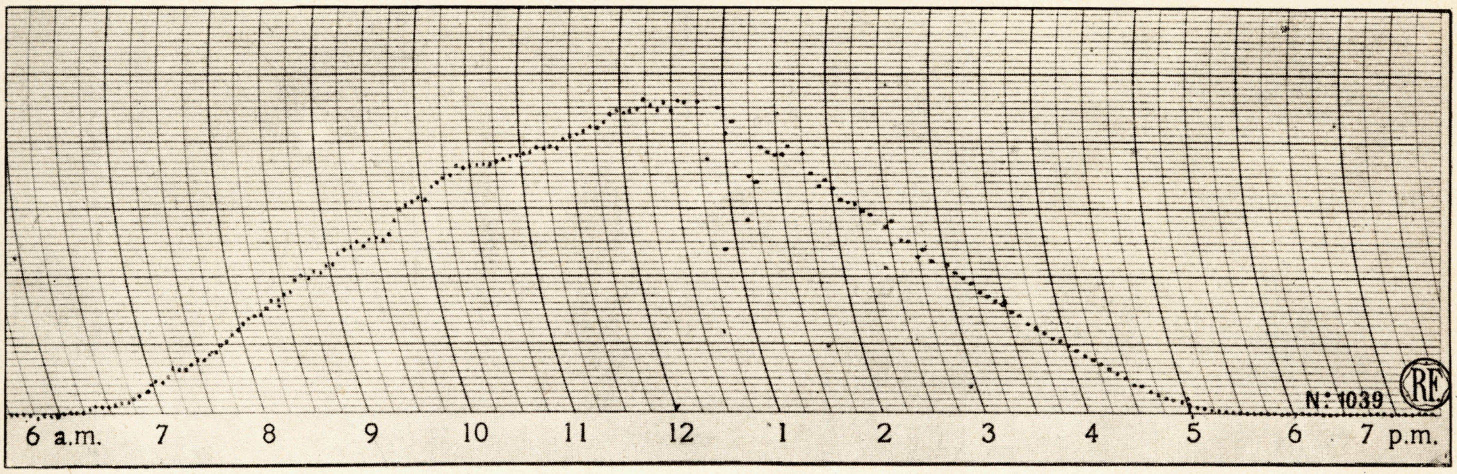

FIG. 5.—Record obtained with a solarigraph on October 4, 1926, at the Solar Radiation Observatory of the U. S. Weather Bureau, American University, District of Columbia

In some galvanometers (millivoltmeters) a slight tapping helps to accelerate the movements of the needle.

The scale of the solarimeter has 100 divisions (0–100) and additional resistances, R_{sol} and R_{pyr} (fig. 1), are so chosen that the coefficients (value of one scale division in absolute units) represent certain determined and round numbers. The coefficients are generally expressed in gram-calories per square centimeter per minute, but a corresponding value for milliwatts per cm^2 or other unit can easily be deduced.

For test purposes the pyrheliometric tube is connected and the contact screws placed at 2 and I (their neutral positions); then two additional resistances R_{pyr} and R_{sol} are included. The deflections of the galvanometer needle when the pyrheliometer tube is used are very nearly proportional to values obtained simultaneously with a normal pyrheliometer. Dividing the value of the latter in gram-calories per minute per $cm.^2$ by the number of divisions on the solarimeter scale, the coefficient for the normal pyrheliometer is directly obtained. If the contact screws are placed at 2_{bis} and I_{bis} or other combinations are used (instead of at 2 and I), the value of the coefficient is smaller and must be determined by comparisons of readings with different resistances.

The value 0.02 (100 scale divisions equal to 2 gram-calories per minute per cm^2) is generally used to convert the deflections (by pyrheliometric connections with the contact screws at 2 and I), in gram-calories per min. per $cm.^2$ If the additional resistance R_{pyr} and R_{sol} are not conveniently chosen by the manufacturer, the observer may easily obtain this coefficient by inserting in series with the ordinary wire connection from the solarimeter box to the pyrheliometer tube several inches of high-resistance manganin wire lead. The proper length of this lead necessary to obtain the correct coefficient is obtained by the cut-and-try method, using a standard pyrheliometer for test purposes.

The testing of the solarimetric pile is somewhat more complicated than that of the pyrheliometric tube. The pile, under its hemispherical glass cover, receives not only direct solar radiation, but also diffuse sky radiation; furthermore, solar radiation acting on the horizontal solarimetric pile is always smaller (proportional to cosines of the zenithal distance of the sun) than simultaneous intensity at normal intensity.

It follows that in order to compare the solarimeter readings, giving the total radiation from the sun and sky on a horizontal surface with simultaneous readings of a pyrheliometer exposed at normal incidence to the sun alone, the following computations must be made:

(*a*) The sky radiation must be separately observed by using a simple solar screen (see solar screen designed by Doctor H. H. Kimball, fig. 4), which is placed between the sun and the solarimeter pile; in this case only the diffuse radiation from the sky gives the solarimetric deflection.

(*b*) The value of the sky radiation is then subtracted from the ordinary solarimetric readings (without solar screen), and thus the value of the sun's radiation only is obtained.

(*c*) The latter value if compared with the simultaneously obtained solar radiation value, using a normal pyrheliometer exposed perpendicularly to the sun's rays, by multiplying it by cosines of the corresponding zenithal distance of the sun, or, which comes to the same thing, by the sine of the sun's altitude. Thus the coefficient for solarimetric readings is directly calculated.

The following example shows clearly the necessary steps:

[AMERICAN UNIVERSITY, WASHINGTON, D. C., OCTOBER 22, 1926]

(A)

11:26 to 11:35 a. m. (standard time) corresponding to 11:33 to 11:42 a. m., true solar time.

Zero position before reading	0.4
Solarimeter reading of sun and sky	28.0
Zero position after reading	.1
Solarimeter reading (corrected) of sun and sky	27.7

(B)

Solarimeter reading (deflection) with solar screen	2.9
Zero position (two readings, before and after sky deflection, mean value)	.2
Solarimeter reading (corrected) of sky only	2.7

(C)

Average value 11:33 to 11:42 a. m. (true solar time) of the solar radiation intensity obtained with a Marvin pyrheliometer (No. 3) was 1.17 gr. cal. per min. per $cm.^2$ (zenithal distance of the sun at 11:38 a. m. true solar time, is 50°.1).

The coefficient K for solarimeter No. 4855 will therefore be—

$$K=\frac{1.17\times\cos 50^{\circ}.1}{27.7-2.7}=\frac{0.749}{25.0}=0.03$$

The value 0.03 is obtained with additional resistance R_{sol} (contact screws at 2 and I). When this resistance R_{sol} is eliminated (by putting the small contact-screw in I_{bis} instead of I), the solarimetric coefficient will be smaller. It is generally nearly 0.02 in this case (contact-screws at 2 and I_{bis}).

If a coefficient value greater than 0.03 is desired, it can be obtained by the addition of a convenient length of small manganin lead to the resistance R_{sol}. In this case the additional leads must be attached to the special bobbin R_{sol} placed inside the solarimeter box. Although practically such tests should and will be made in an observatory and the solarimeters delivered to the observers with the corresponding coefficients, it is not amiss to indicate the procedure for testing for observers who would not only be willing but who would have the proper standard normal instruments in their possession to enable them to repeat the standardization.

We may add that the solar screen of Doctor Kimball's design, illustrated in Figure 4, was extensively used in 1914 at Mount Weather, Va., for standardizing a Callendar recording pyrheliometer where a glass cover is used. The valuable results of Doctor Kimball's painstaking investigations (see MONTHLY WEATHER REVIEW, August, 1914), give many hints for testing horizontally exposed pyrheliometers.

RECORDING SOLARIMETER (SOLARIGRAPH)

Though, as pointed out above, the solarimeters are made primarily as a portable instrument for direct short exposure to the sun, and not for permanent outdoor installation, they can also be adapted for recording purposes. (See fig. 3.) In that case the same solarimeter pile is installed on a special holder, which should be permanently fastened at a convenient place outdoors.

The solarimeter pile, always hermetically sealed in dry air, can remain permanently in the open air without danger of condensation forming inside its glass cover, but the outer surface of the glass should be cleaned from time to time. By means of flexible leads this instrument is connected to the recording galvanometer, which should remain inside a building. The needle galvanometer (of a simple millivoltmeter type) mechanically recording, chosen for the solarigraphs, is similar to that used for the thermoelectric pyrheliographs manufactured by Jules Richard in Paris.

The new Richard recording galvanometers (millivoltmeters) are, however, specially adapted for solarigraphs. By using coils with low resistance, approximately the same as that of the solarimetric piles, a marked increase in deflections was obtained. The sensitivity of the solarigraph is sufficient to get a deflection even with cloudy weather; characteristic variations are obtained on the diagrams, provided the thickness and transparency of the cloud changes.

In Figure 5 is shown a solarigraph record obtained on October 4, 1926, at the Solar Radiation Observatory of the U. S. Weather Bureau, American University, District of Columbia, where, through the courtesy of Professor Marvin, our solarigraph was calibrated. I am particularly indebted to Dr. H. H. Kimball, in charge of the Solar Observatory, and to his assistant, Mr. Irving F. Hand, for their kind help and very valuable suggestions during my stay at the observatory.

The record of October 4, 1926 (fig. 5); was obtained during a mostly clear day, although some clouds (visible between 12:30 and 1:30 p. m.) caused certain irregularities in the curve. Such a solarigram can be used for calculations, for instance, by planimetric methods, of the daily sums of solar and sky radiation on a horizontal surface.

Both direct-reading and recording solarimeters are made with two or more ranges, which permit the obtaining of greater deflections during cloudy or winter days with low sun. A very useful and important feature of the solarimeter is that it is able to give interesting records even on cloudy days, when the normal pyrheliometer gives no indication at all.

NOTES, ABSTRACTS, AND REVIEWS

WILLIS ISLAND METEOROLOGICAL STATION

A meteorogical station on an island so small and low and far to windward of large land masses that its climate is almost as purely marine as if the island were a ship is Willis Island in the south Pacific east of Australia. Willis Island lies 250 miles east of the north Queensland coast, approximately in latitude 16° S., longitude 15° W. Above ordinary seas it is less than 500 yards long and about 200 yards wide, and its summit is just under 30 feet above low water. Across it blows the southeast trade at a velocity that rarely is less than 5 m. p. h., and frequently is over 20 m. p. h. for long periods.

It is some six years since the Commonwealth Bureau of Meteorology established a station on the island. This was done largely to keep an eye on tropical cyclones approaching the coast of Australia. In addition to the usual surface observations, a series of pilot-balloon observations has made possible a preliminary analysis of free-air conditions in this trade-wind region. The following excerpts are adapted from a paper dealing with the seasons 1922–23 and 1923–24, by Dr. E. Kidson, entitled: "Observations from the Willis Island Meteorological Station," in volume 17 of the Report of the Australasian Association for the Advancement of Science, 1924 (the Government Printer, Adelaide, 1926).

To most people it is the winds of Willis Island that will be of greatest interest. Except for short breaks in the cyclone season, due either to passing cyclones or to the advent of the northwest monsoon, the southeast trade blows almost continuously, the mean direction being from southeast by east. In the six months November to April about 70 per cent of the winds are from between south and east, and in the winter months between 80 and 90 per cent. As far as the results go, they indicate that the wind velocity is greatest in the months when the pressure is rising, with a maximum in April, and least when the pressure is falling. The diurnal variation of the wind is especially interesting, since it can not be affected to any large extent by the land. * * * There is a maximum frequency of easterly winds in the hours just before sunrise. This is followed by a maximum for the east-southeasterlies in the three hours preceding noon. Thereafter the southerly component becomes more prominent, and south-easterly to southerly winds have their maximum frequency during the 16 hours to 18 hours period. In the northwesterly quadrant the winds tend to become more northerly in the forenoon hours and more westerly in the afternoon. * * *

The lowest velocity is recorded in the early afternoon, at about 14 hours or 15 hours. After sunset there is a fairly rapid increase to a maximum at about 22 hours to 23 hours.

The diurnal variation seems to consist chiefly, therefore, in the production of an easterly component in the morning and a westerly in the afternoon. The mean velocity is 15.7 miles per hour (7.1 meters per second). * * *

Pilot balloon ascents were made once daily during the seasons 1922–23 and 1923–24. Among the first points noted with regard to the ascents are the small change in direction with height and the low height at which a maximum velocity is reached. * * * It must be remembered that for the upper levels results are available for clear days and days of light wind only, and consequently they may not represent mean conditions. It is unlikely, however, that the impressions they give are very misleading. Above 1 km. the direction gradually becomes more variable, southerlies and westerlies being more frequent. Above 4 km. it would seem that southwesterlies prevail, while at still higher levels it is most probable that northwesterlies are the most frequent. At the high levels winds from the northeasterly quadrant are the least frequent.

The winds do not in every case veer in the lower levels from the surface direction. In fact, the ratio of the number that back to the number that veer between 50 m. and 450 m. is 1 to 1.8. This ratio was obtained in both seasons, and is the same for winds of all types. The reason for this constancy is not clear. The northwesterly winds veer to a greater extent than the south-easterly.

Such evidence as there is tends to show that in general the velocities begin to fall off before 1 km. is reached and continue to do so over the range covered by the balloon ascents. Strong winds are rare, the strongest gusts recorded on the surface being about 18 m/s (40 m. p. h.). Velocities greater than this were only rarely met with in the first kilometer above the surface, though 29 m/s (65 m. p. h.) was reached on one occasion. Were a cyclone to approach very near the island these speeds would, of course, be greatly exceeded.—*B. M. V.*

THE CAUSES OF GLACIATIONS

551.532(048)

In a review of Prof. A. P. Coleman's "Ice Ages: Recent and Ancient" (Macmillan, 1926), C. E. P. Brooks writes as follows (in *Nature*, London, August 28, 1926), touching the far-from-solved problem of the causes of glaciations:

* * * These phenomena offer a definite meteorological problem, which the author sets out clearly in words which are worth quoting:

"Under normal conditions the world has a relatively mild and equable climate with no permanent ice at low levels even in the polar regions.

"From time to time * * * there have been relatively short periods of cold accompanied by a great extension of mountain glaciers, and sometimes also by the formation of ice sheets at low levels. In the most severe visitation of the kind ice sheets invaded the Tropics on three or perhaps four continents.

"Ice ages are, in most cases, broken by interglacial periods of milder climate. Sometimes this occurs two or three or more times, indicating a comparatively rapid oscillation from cold to warm and warm to cold.

"All parts of the world have their temperature lowered during an ice age, the Tropics as well as the temperate and Arctic zones."

The author then turns to the consideration of causes, but gives only a rather mechanical discussion of the various theories of climatic change which have been put forward from time to time. Wegener's theory of continental drift is mentioned, but without